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ABSTRACT

This annual report of progress of the Institute for Mathematical Studies covers four main projects: (1) computer generated speech, (2) complex teaching programs with audio, (3) teaching reading with audio, and (4) speech recognition. Thirty-seven references to research on the use of computers and the teaching of primary reading are included. A listing of 15 technical reports issued by the institute during the reporting term is appended. (DS)

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Annual Technical Report

July 1, 1974 - June 30, 1975

Research on Uses of Audio and Natural-language Processing in Computer-assisted Instruction

Stanford University
Institute for Mathematical Studies in the Social Sciences
Stanford, California 94305

BEST COPY AVAILABLE

Principal Investigator: Patrick Suppes

Project Starting Date: July 1, 1974

Expected Termination Date: June 30, 1977

NSF Grant No. EPP74-15016 A01

U S DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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I. Project Objectives

In the initial proposal, project objectives were summarized under the following four main headings. We quote from the abstract of the initial proposal.

"1. Computer-generated speech. The concern here is development of sophisticated and efficient methods of generating speech from digitally stored parameters.

"2. Complex teaching programs with audio. Concentration will be on college-level logic courses and tutorial instruction in elementary-school mathematics.

"3. Teaching reading with audio. The concern will be with efficient and sophisticated approaches to the organization of curriculum in initial reading skills.

"4. Speech recognition. A limited set of experiments will be concerned with voice-to-voice interaction between student and computer system."

In the following sections, we comment on the work done to reach these four objectives and on the problems encountered. We have worked within the general approach to computer-assisted instruction developed at the Institute over more than a decade of research and development.

1. Computer-generated Speech

The Institute has done extensive work on computer-generated speech for more than five years. The approach taken during the period covered by this annual technical report was described in a preliminary report by Gerard Benbassat and William R. Sanders transmitted to the Foundation in 1974. There was extensive work on completion of the hardware, and the new audio system just became operational at the end of this reporting period.

The new synthesizer is capable of generating 48 virtual channels. The hardware is divided into two major parts: a digital filter that does the actual voice synthesis and a prosodic calculator that interfaces to the PDP-10, performs necessary data conversions, and performs the appropriate prosodic computations as specified by the user. A vocabulary of 12,000 words has been selected from a number of the Institute's computer-assisted-instruction programs and has been recorded and digitized. An analysis program developed in the Institute reduces the number of bits required to represent the voice from 120,000 bits per second to less than 8,000 bits per second.

A description of the pitch-extraction algorithms is given in an unpublished technical report by Gerard Benbassat (1975). This technical report will shortly be circulated and deposited in the ERIC Documentation Center. The initial draft of the technical report by Benbassat is transmitted with this annual technical report.

In addition, during this period of completion of the hardware of the new digital synthesizer, operational use continues of the earlier computer-generated-speech synthesizer that has been used extensively in the teaching of initial reading and to some extent in the teaching of foreign languages. An account of the research work flowing from this operational use of synthesized speech is mentioned below.

We mention at this point Technical Report 237 by Raugh and Atkinson and Technical Report 256 by Raugh, Schupbach, and Atkinson:

> Atkinson, R. C., and Raugh, M. R., An application of the mnemonic keyword method to the acquisition of a Russian vocabulary, Tech. Rep. 237, October 4, 1974.
>
> Raugh, M. R., Schupbach, R. D., and Atkinson, R. C., Teaching a large Russian language vocabulary by the mnemonic keyword method, Tech. Rep. 256, July 11, 1975.

These technical reports use the speech synthesizer for the study of the acquisition of Russian vocabulary by Stanford students. The specific research was supported by an Office of Naval Research contract, but the experiment depended upon use of the digital synthesizer that has been developed at Stanford primarily on the basis of earlier Foundation support.

2. Complex Teaching Programs with Audio

During the period covered by this technical report, audio was not implemented in the complex teaching programs, but rather the main effort was devoted to developing the framework and doing the extensive and sophisticated background programming needed to bring the complex teaching programs to an operational state. The most important accomplishment of this period was implementation of the course in axiomatic set theory and all of the proof procedures required to make this course operational.

A good description of the programming work required is to be found in Technical Report 262:

> Smith, R. L., Graves, W. H., Blaine, L. H., and Marinov, V. G., Computer-assisted axiomatic mathematics: Informal rigor, Tech. Rep. 262, 1975.

This paper was given by Dr. Smith at the Second World Conference on Computer Education held in Marseilles, France in September 1975. Additional information about the set theory course is contained in Technical Reports 261 and 265:

Suppes, P., Impact of computers on curriculum in the schools and universities, Tech. Rep. 261, 1975.

Suppes, P., Smith, R., and Beard, M., University-level computer-assisted instruction at Stanford: 1975, Tech. Rep. 265, October 15, 1975.

The course in axiomatic set theory was brought to the operational stage during 1974-75 and was offered in each of the three terms of the 1974-75 academic year. However, it was only during the spring quarter that the staff felt that the course had reached an acceptable level of implementation.

We shall not attempt in this annual report to give a technical description of the proof procedures for interactive use by students. Readers interested in examples of proofs are referred to the proof of the classical Schroeder-Bernstein theorem exhibited in Technical Report 262 referred to above. Extensive analysis of student proofs is planned for the future, and subsequent technical reports will deal with this subject. From a programming standpoint, the course in axiomatic set theory represented a major effort beyond that required for the CAI course in elementary logic. More sophisticated proof procedures that are closer to informal mathematical proofs were required in order to have a viable course. In principle, of course, students could give a completely formal proof in the sense of first-order logic, as they mainly do in the logic course, but this would really make the proofs of the classical theorems of set theory impossibly long and complex. The surrounding curriculum has been taken rather directly from Suppes' Axiomatic Set Theory (1960) with changes as appropriate to the new format.

The set-theory proof checker will provide the semantic base for work on audio and natural language in the forthcoming year, using the student's developing proof as the object of the dialogue. The vocabulary of set theory is rather fixed and small, but nevertheless there is need for highly interactive composition of sentences with accurate stress and intonation of operator words. This makes it an ideal initial application for the audio system.

Introduction to logic. Computer-assisted instruction in Introduction to Logic at Stanford has been under way for several years. During 1974-75 the course achieved a relatively stable format after the program was rewritten under the direction of Dr. Robert L. Smith and Mr. Lawrence Markosian in order to increase the efficiency of the course and to incorporate features from set theory as they became available.

Using these new features, several curriculum extensions have been undertaken. The objective has been to develop a number of individualized strands that students can choose from once they have finished the common core of the course for a pass level. During 1974-75 two individualized strands became operational. One has been concerned with Boolean algebra and the qualitative foundations of probability; the other has been an axiomatic development and proof of the relevant theorems in social choice theory growing out of the classical work of Kenneth J. Arrow.

An audio application for the logic course is under way that will form the basis for a new section relating English to the formalism of first order logic.

Experiments with children learning computer programming. During 1974-75, Mr. Steven Weyer and Mr. Alex Cannara completed the write-up of experiments conducted under the earlier Foundation grant to the Institute. These experiments are reported in Technical Report 250:

> Weyer, S. A., and Cannara, A. B., Children learning computer programming: Experiments with languages, curricula and programmable devices, Tech. Rep. 250, January 27, 1975.

The technical report analyzes and compares the learning of two computer languages, one the well-known language, LOGO, and the other a pseudo assembly language, SIMPER, developed by Paul Lorton and John Slimick at the Institute several years ago. It should be mentioned that, among other things, the students in this experiment used the digitized synthesizer to program audio messages.

The work on complex teaching programs has also been concerned with deepening our understanding of natural-language processing. A good example of the extensive technical efforts under way in this area is to be found in Technical Report 238:

> Smith, R. L., Smith, N. W., and Rawson, F. L., CONSTRUCT: In search of a theory of meaning, Tech. Rep. 238, October 25, 1974.

Two technical reports dealing with work in the course in Introduction to Logic, partly resulting from research begun prior to July 1, 1974, were issued during this period and contain extensive data on the earlier CAI course in logic. Technical Report 239 by Dr. Adele Goldberg and Professor Suppes gives detailed data on the CAI course in logic at the university level during the period prior to 1974-75. Technical Report 258 by Macken, van den Heuvel, T. Suppes, and P. Suppes has as part of its report a detailed analysis of the home-based instruction in logic with a group of gifted students, work which was initially supported under the prior grant from the Foundation to the Institute.

> Goldberg, A., and Suppes, P., Computer-assisted instruction in elementary logic at the university level, Tech. Rep. 239, November 8, 1974.

> Macken, E., van den Heuvel, R., Suppes, P., and Suppes, T. Study of needs and technological opportunities in home-based education, Tech. Rep. 258, July 28, 1975.

3. Teaching Reading with Audio

The research under this heading was under the direction of Professor Richard C. Atkinson, who has been on leave since June 1975 to assume the position of Deputy Director of the Foundation. During the period covered by this annual report, Professor Atkinson and his younger

colleagues continued the extensive work on complex instructional strategies undertaken over the past several years. The environment of application has ranged from the teaching of initial reading with audio to primary-grade children to the teaching of computer programming to college-level students.

Work on the application of the mnemonic keyword method to the acquisition of a foreign vocabulary is reported in the two technical reports already mentioned, Technical Reports 237 and 256.

The general approach in developing complex instructional strategies is set forth in Technical Report 240 by Professor Atkinson:

Atkinson, R. C., Adaptive instructional systems: Some attempts to optimize the learning process, Tech. Rep. 240, November 20, 1974.

Additional technical reports dealing with this work are Technical Reports 260, 263, and 264:

Barr, A., Beard, M., and Atkinson, R. C., The computer as a tutorial laboratory: The Stanford BIP project, Tech. Rep. 260, August 22, 1975.

Barr, A., Beard, M., and Atkinson, R. C., Information networks for CAI curriculum, Tech. Rep. 263, 1975.

Chant, V. G., and Atkinson, R. C., Application of learning models and optimization theory to problems of instruction, Tech. Rep. 264, October 10, 1975.

Some of the work contained in these technical reports was also supported by the Office of Naval Research as well as the present grant.

The period covered by this annual report marks the conclusion of an extensive period of research by the Institute in the teaching of initial reading with audio. With Professor Atkinson's departure to the Foundation at the end of this period, it was decided to terminate this research on July 1, 1975.

Because this effort has been perhaps the most extensive in the world to use computers to teach primary reading, we list here the full set of publications that have been produced by this research over the years including Technical Report 249, issued during the period of this annual report.

Atkinson, R. C., and Hansen, D. Computer-assisted instruction in initial reading: The Stanford project. Reading Research Quarterly, 1966, 2, 5-25.

Rodgers, T. S., Linguistic considerations in the design of the Stanford computer-based curriculum in initial reading, Tech. Rep. 111, June 1, 1967.

Knutson, J. M., Spelling drills using a computer-assisted instructional system, Tech. Rep. 112, June 30, 1967.

Atkinson, R. C., Instruction in initial reading under computer control: The Stanford project, Tech. Rep. 113, July 14, 1967.

Atkinson, R. C. Reading instruction under computer control. American School Board Journal, 1967, 155, 16-17.

Atkinson, R. C. Learning aspects of computer-assisted instruction. In R. W. Gerard (Ed.), Computers and education. New York: McGraw-Hill, 1967. Pp. 11-63.

Wilson, H. A., and Atkinson, R. C., Computer-based instruction in initial reading: A progress report on the Stanford project, Tech. Rep. 119, August 25, 1967.

Fishman, E. J., Keller, L., and Atkinson, R. C. Massed vs. distributed practice in computerized spelling drills. Journal of Educational Psychology, 1968, 59, 290-296.

Atkinson, R. C. A reply to Professor Spache's article "A reaction to computer-assisted instruction in initial reading." Reading Research Quarterly, 1968, 3, 418-420.

Atkinson, R. C. The computer as a tutor. Psychology Today, January 1968.

Atkinson, R. C. The role of the computer in teaching initial reading. Childhood Education, 1968, 44, 464-470.

Atkinson, R. C. Computer-based instruction in initial reading. Proceedings of the 1967 Invitational Conference on Testing Problems. Princeton, N.J.: Educational Testing Service, 1968. Pp. 55-66.

Atkinson, R. C. Computerized instruction and the learning process. American Psychologist, 1968, 23, 225-239.

Atkinson, R. C. Learning to read under computer control. Programmed Learning and Educational Technology: British Journal of the Association for Programmed Learning, 1968, 5, 25-37.

Atkinson, R. C. Computer-assisted learning in action. Proceedings of the National Academy of Sciences, 1969, 63, 588-594.

Atkinson, R. C. Information delay in human learning. Journal of Verbal Learning and Verbal Behavior, 1969, 8, 507-511.

Atkinson, R. C., Holmgren, J. E., and Juola, J. F. Processing time as influenced by the number of elements in a visual display. Perception and Psychophysics, 1969, 6, 321-326.

Atkinson, R. C. Models for memory. In F. Bresson and M. de Montmollin (Eds.), Sciences du comportement: La recherche en enseignement programme. Paris: Dunod, 1969. Pp. 75-94.

Cermak, G., Schnorr, J., Buschke, H., and Atkinson, R. C. Recognition memory as influenced by differential attention to semantic and acoustic properties of words. Psychonomic Science, 1970, 19, 79-81.

Atkinson, R. C., Fletcher, J. D., Chetin, H. C., and Stauffer, C. M. Instruction in initial reading under computer control: The Stanford project. In A. Romano and S. Rossi (Eds.), Computer in education. Bari, Italy: Adriatica Editrice, 1971. Pp. 59-99.

Atkinson, R. C., and Wickens, T. D. Human memory and the concept of reinforcement. In R. Glazer (Ed.), The nature of reinforcement. New York: Academic Press, 1971. Pp. 66-120.

Atkinson, R. C., and Juola, J. F. Memory scanning for words versus categories. Journal of Verbal Learning and Verbal Behavior, 1971, 10, 52-57.

Atkinson, R. C., and Fletcher, J. D. Teaching children to read with a computer. The Reading Teacher, 1972, 25, 319-327.

Fletcher, J. D., and Atkinson, R. C. An evaluation of the Stanford CAI program in initial reading. Journal of Educational Psychology, 1972, 63, 597-602.

Atkinson, R. C., and Paulson, J. A. An approach to the psychology of instruction. Psychological Bulletin, 1972, 78, 49-61.

Atkinson, R. C. Ingredients for a theory of instruction. American Psychologist, 1972, 27, 921-931.

Chant, V. G., and Atkinson, R. C. Optimal allocation of instructional effort to interrelated learning strands. Journal of Mathematical Psychology, 1973, 10, 1-25.

Atkinson, R. C., and Juola, J. F. Factors influencing speed and accuracy of word recognition. In S. Kornblum (Ed.), Attention and Performance IV. New York: Academic Press, 1973. Pp. 583-612.

Atkinson, R. C., Fletcher, J. D., Lindsay, E. J., Campbell, J. O., and Barr, A. Computer-assisted instruction in initial reading: Individualized instruction based on optimization procedures. Educational Technology, September 1973, pp. 27-37.

Atkinson, R. C. Entwurf einer theorie des lehrens. In H. B. Pollett and K. Weltner (Eds.), Fortschritte und Ergebnisse der Bildungstechnologie. Munich: Ehrenwirth Verlag, 1973. Pp. 58-75.

Paulson, J. A., An evaluation of instructional strategies in a simple learning situation, Tech. Rep. 209, May 1973.

Manelis, L., and Atkinson, R. C. Tachistoscopic recognition of syllabicated words. The Quarterly Journal of Experimental Psychology, 1974, 26, 158-166.

Atkinson, R. C., and Juola, J. F. Search and decision processes in recognition memory. In D. H. Krantz, R. C. Atkinson, R. D. Luce, and P. Suppes (Eds.), Contemporary developments in mathematical psychology (Vol. 1). Learning, memory, and thinking. San Francisco: Freeman, 1974. Pp. 243-293.

Atkinson, R. C., Herrmann, D. J., and Wescourt, K. T. Search processes in recognition memory. In R. L. Solso (Ed.), Theories in cognitive psychology: The Loyola Symposium. Hillsdale, N.J.: Erlbaum Associates, 1974. Pp. 101-146.

Atkinson, R. C. Teaching children to read using a computer. American Psychologist, 1974, 29, 169-178.

Atkinson, R. C., and Wescourt, K. T. Some remarks on a theory of memory. In P. M. A. Rabbitt and S. Dornic (Eds.), Attention and performance V. London: Academic Press, 1975. Pp. 485-498.

Campbell, J. O., Lindsay, E. J., and Atkinson, R. C., Predicting reading achievement from measures available during computer-assisted instruction, Tech. Rep. 249, January 20, 1975.

As this phase of research has been brought to a conclusion, it is the judgment of a number of different individuals that computer-assisted instruction in primary reading has now passed beyond the research stage and is ready for development and operational use in schools. We believe that the research that has been reported from the Institute over a number of years on these matters forms a very solid basis for subsequent operational efforts.

4. Speech Recognition

As a continuation of work done under the previous grant from the Foundation, a limited effort in speech recognition was undertaken during this period. This effort was meant to extend the work reported in Technical Report 223:

Danforth, D. G., Rogosa, D. R., and Suppes, P., Learning models for real-time speech recognition, Tech. Rep. 223, January 15, 1974.

During the period covered by this annual report, the speech-recognition project concentrated on real-time recognition of single utterances spoken over the telephone. We were particularly interested in applications of speech recognition to computer-assisted instruction using the standard home telephone as an inexpensive CAI terminal. Consequently, the recognition system had to perform under the constraints of real-time recognition on a timesharing computer system. We chose as a curriculum for investigation the work in spelling customary at an elementary-school level. One of the reasons for this choice was the practical possibility of implementing in real time and on a timesharing system the recognition of the 26 letters of the alphabet. Our objective was to match or exceed human performance for situations where only acoustical knowledge is available, that is, situations in which very little contextual knowledge exists to aid the listener.

We experimented with various recognition models as part of this task. Details of the work accomplished is described in an unpublished technical report by J. Terhune, D. Rogosa, and P. Suppes, "Investigation of Single Letter Recognition on the IMSSS Speech Recognition System." A preliminary draft of this technical report has been previously transmitted to the Foundation.

In view of the restricted budget during 1974-75 it was decided that this area should receive restricted effort and that the effort should be concluded during the period covered by this report. It was our judgment that, although a practical system could be put in place, the costs of doing so both in terms of software and in terms of computer time were excessive for the restricted funds available to the project.

On the other hand, it was the judgment of project personnel that restricted systems of the kind developed could be put in place and could be extensively experimented with if funds were available. There were no serious technical constraints in operating a speech-recognition system at the level required for the work in spelling and also for the earlier reported work (Technical Report 223) in mental arithmetic requiring spoken-number recognition.

II. Important Changes to the Original Plans

As indicated in the abstract quoted above of the initial proposal, research and development work on tutorial instruction in elementary-school mathematics was initially planned as part of this proposal. However, the initial budget request was reduced in the final decision on funding and it was necessary therefore to eliminate this part of the initial project from coming to completion except for some preliminary initial developments. It is the judgment of project personnel that tutorial instruction in elementary-school mathematics, especially with the use of digitized audio is still a natural point for research and development in computer-assisted instruction; but it seems unlikely that substantial funding will be available for this effort in the near future.

Generally speaking, with the continued inflation and continued budget restrictions at the Foundation, it was found that our initial proposal covered too many topics. During the course of the year the work in speech recognition had to be brought to a conclusion and the work in tutorial instruction in elementary-school mathematics was only begun on an exploratory basis. Much of the research directed toward the natural-language problems of elementary mathematics was applied to the set theory program. Initially it was hoped that part of the funding for the effort in tutorial instruction in elementary-school mathematics would also be funded by a grant from the Bureau for the Educationally Handicapped, U.S. Office of Education, but this proposal was not funded, and consequently the effort in this area had to be terminated.

With the termination of the work in initial reading at the elementary-school level, the tutorial instruction in elementary-school mathematics, and the work in speech recognition, the Institute brought to a close by July 1, 1975, all of its research in the implementation of computer-assisted instruction at the school level. Beginning July 1, 1975, the focus of the research is entirely on research and development of courses and techniques at the university level. For this reason, the period covered by this technical report marks the end of an important phase in the Institute's history of research and development in computer-assisted instruction. On June 30, 1975, the last terminals present in elementary schools were removed. The association with Brentwood School in East Palo Alto began in 1964 and thus lasted for a period of more than 11 years.

During this 11-year period we believe that the Institute has made significant contributions to the research and development of computer-assisted instruction at the school level. Programs that derive from the initial work at the Institute are now in use in the basic skill areas of elementary mathematics, reading, and language throughout the United States, especially with disadvantaged students.

As we now focus on university-level instruction and at a considerably more complex level of interaction between student and program, we feel that we will be fortunate to have the same kind of impact on university-level instruction that we have had in the past on instruction in basic skills at the elementary-school level.

Summary of Technical Reports Issued During This Reporting Period

No.	Title	Author	Date
237	An application of the mnemonic keyword method to the acquisition of a Russian vocabulary	R. C. Atkinson M. R. Raugh	October 4, 1974
238	CONSTRUCT: In search of a theory of meaning	R. L. Smith N. W. Smith F. L. Rawson	October 25, 1974
239	Computer-assisted instruction in elementary logic at the university level	A. Goldberg P. Suppes	November 8, 1974
240	Adaptive instructional systems: Some attempts to optimize the learning process	R. C. Atkinson	November 20, 1974

250	Children learning computer programming: Experiments with languages, curricula and programmable devices	S. A. Weyer A. B. Cannara	January 27, 1975
256	Teaching a large Russian vocabulary by the mnemonic keyword method	M. R. Raugh R. D. Schupbach R. C. Atkinson	July 11, 1975
258	Study of needs and technological opportunities in home-based education	E. Macken R. van den Heuvel P. Suppes	July 28, 1975
260	The computer as a tutorial laboratory: The Stanford BIP project	A. Barr M. Beard R. C. Atkinson	August 22, 1975
261	Impact of computers on curriculum in the schools and universities [In O. Lacarme & R. Lewis (Eds.), Computers in education, IFIP (Part 1). Amsterdam: North-Holland, 1975. Pp. 173-179.]	P. Suppes	Reprint, 1975
262	Computer-assisted axiomatic mathematics: Informal rigor [In O. Lacarme & R. Lewis (Eds.), Computers in education, IFIP (Part 2). Amsterdam: North-Holland, 1975. Pp. 803-809.]	R. L. Smith W. H. Graves L. H. Blaine V. G. Marinov	Reprint, 1975
263	Information networks for CAI curriculum [In O. Lacarme & R. Lewis (Eds.), Computers in education, IFIP (Part 1). Amsterdam: North-Holland, 1975. Pp. 477-482.]	A. Barr M. Beard R. C. Atkinson	Reprint, 1975
264	Application of learning models and optimization theory to problems of instruction	V. G. Chant R. C. Atkinson	October 10, 1975
265	University-level computer-assisted instruction at Stanford: 1975	P. Suppes R. Smith M. Beard	October 15, 1975
...	Investigation of single letter recognition on the IMSSS speech recognition system	J. Terhune D. Rogosa P. Suppes	Preliminary draft
...	Time-domain two-dimensional pitch detection	G. Benbassat	Preliminary draft